

POLYETHYLENE COMPOSITIONS
FOR ROTATIONAL MOLDING

1. **CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] The present application claims the benefit of U.S. Provisional Applications No. 60/414,952, filed October 1, 2002 and 60/424,535, filed November 7, 2002, said applications incorporated herein by reference.

2. **FIELD OF THE INVENTION**

[0002] This invention relates to thermoplastic compositions of polyethylene polymers suitable for fabrication into useful products by rotational molding.

3. **BACKGROUND**

[0003] Rotational molding or rotational casting, more commonly known as rotomolding, is widely used for molding hollow articles, and can be used to mold both small and large containers, such as tanks of typically 19 L to 57,000 L. Such rotomolded tanks are utilized in agricultural, chemical and recreational vehicle industries. Rotomolded containers are used for packaging and material handling, particularly as container articles for fluids or solids. Rotational molding is also used for portable toilets, instrument and battery cases, light globes, vacuum cleaner and scrubber housings, toys and garbage containers. The process is relatively less expensive and easy to use for polymer processing than other known means and has been increasing in use.

[0004] To rotomold a part, a powdered, polymeric resin is charged inside a mold shell, which is then, typically, rotated on two axes and heated to cause the melting resin to adhere to the inside of the mold. After sufficient heating time, the mold is moved to a cooling chamber, and after cooling, the molded part is removed to begin another molding cycle. More detailed discussion of rotomolding may be found in Modern Plastics Encyclopedia 1990, pages 317-318, and in Encyclopedia of Polymer Science and Engineering, pages 659-670 (J. Wiley & Sons, 1990).

[0005] Rotational molding primarily uses polyolefin resins, with thermoplastic polymers of ethylene being principally used. Key properties for rotationally

molded parts include appearance, and especially in the case of containers, resistance to puncture or rupture, chemical resistance and for extended periods of usefulness, resistance to environmental stress cracking. Low density polyethylene (LDPE) with a density of about 0.900 to about 0.925 g/cm³, linear low density polyethylene (LLDPE) with a density of about 0.926 to about 0.940 g/cm³, and high density polyethylene (HDPE) with a density of about 0.940 to about 0.960 g/cm³ are used in rotomolding applications. LLDPE is said to be preferred for its excellent low temperature impact strength and good environmental stress crack resistance ("ESCR").

[0006] Compositions of polyethylene resins have been proposed to improve physical properties, including impact strength, environmental stress crack resistance, and chemical resistance. U.S. Patent No. 4,438,238 describes blends for extrusion processing, injection molding and films where a combination of two ethylene- α -olefin copolymers with different densities, intrinsic viscosities and number of short chain branching per 1000 carbon atoms is attributed with such physical properties. U.S. Patent No. 4,461,873 describes ethylene polymer blends of a high molecular weight ethylene polymer, preferably a copolymer, and a low molecular weight ethylene polymer, preferably an ethylene homopolymer, for improved film properties and environmental stress crack resistance useful in the manufacture of film or in blow molding techniques, the production of pipes and wire coating. EP 0 423 962 describes ethylene polymer compositions particularly suitable for gas pipes said to have improved environmental stress cracking resistance comprising two or more kinds of ethylene polymers different in average molecular weight, at least one of which is a high molecular weight ethylene polymer having an intrinsic viscosity of 4.5 to 10.0 dl/g in decalin at 135 °C and a density of 0.910 to 0.930 g/cm³ and another of which is a low molecular weight ethylene polymer having an intrinsic viscosity of 0.5 to 2.0 dl/g, as determined for the first polymer, and a density of 0.938 to 0.970 g/cm³.

[0007] U.S. Patent No. 5,082,902 describes blends of linear polyethylenes for injection and rotational molding said to have reduced crystallization times with improved impact strength and ESCR. The blends comprise (a) a first polymer having a density of from 0.85 to 0.95 g/cm³ and an MI of 1 to 200 g/10 min, and

(b) a second polymer having a density of 0.015 to 0.15 g/cm³ greater than the density of the first polymer and an MI differing by no more than 50% from the MI of the first polymer. U.S. Patent No. 5,306,775 describes polyethylene blends said to have a balance of properties for processing by any of the known thermoplastic processes, specifically including improved environmental stress crack resistance. These compositions have (a) low molecular weight ethylene resins made using a chromium oxide based catalyst and having a density at least 0.955 g/cm³ and melt index (MI) between 25 and 400 g/10 min and (b) high molecular weight ethylene copolymer resins with a density not higher than 0.955 g/cm³ and a high load melt index (HLMI) between 0.1 and 50 g/10 min.

[0008] U.S. Patent No. 5,382,631 describes linear interpolymer polyethylene blends having narrow molecular weight distribution ($M_w/M_n \leq 3$) and/or composition distribution (CDBI) less than 50%, where the blends are generally free of fractions having higher molecular weight and lower average comonomer contents than other blend components. Improved properties for films, fibers, coatings, and molded articles are attributed to these blends. In one example, a first component is an ethylene-butene copolymer with a density of 0.9042 g/cm³, M_w/M_n of 2.3, and an MI of 4.0 dg/min and a second component is an HDPE with a density of 0.9552 g/cm³, M_w/M_n of 2.8, and an MI of 5.0 dg/min. The blend is said to have improved tear strength characteristics.

[0009] U.S. Patent No. 6,362,270 describes thermoplastic compositions said to be especially suited to rotomolding applications comprising (a) a majority component that may be an ethylene interpolymer having a density greater than 0.915 g/cm³ and preferably a melt index of from about 2 to 500 g/10 min, and (b) an impact additive that may be an ethylene interpolymer having a density less than 0.915 g/cm³ and melt index preferably greater than 0.05 g/10 min and less than 100 g/10 min. Improved physical properties as ascribed to these compositions include improved impact strength and good ESCR.

[0010] There is a continuing need for polyethylene-based compositions of improved environmental stress crack resistance and impact strength, particularly for those that are suitable for rotomolding applications.

4. SUMMARY OF THE INVENTION

[0011] In accordance with the present invention, polyolefin-based blend compositions suitable for rotomolding, rotomolded articles, and processes for rotomolding articles are provided.

[0012] In one embodiment, the invention provides a polyethylene composition including a first polyethylene having a melt index of 0.4 to 3.0 g/10 min and a density of from 0.910 to 0.930 g/cm³; and a second polyethylene having a melt index of 10 to 30 g/10 min and a density of 0.945 to 0.975 g/cm³, wherein the composition has a density of from 0.930 to 0.955 g/cm³ and a melt index of 1.5 to 12 g/10 min, and wherein the first and second polyethylenes differ in density by from 0.030 to 0.048 g/cm³.

[0013] In another embodiment, the invention provides a polyethylene composition including a first metallocene-catalyzed polyethylene having a melt index of 0.4 to 3.0 g/10 min and a density of from 0.910 to 0.930 g/cm³; and a second metallocene-catalyzed polyethylene having a melt index of 10 to 30 g/10 min and a density of 0.945 to 0.975 g/cm³, wherein the composition has a density of from 0.930 to 0.955 g/cm³ and a melt index of 1.5 to 12 g/10 min, and wherein the first and second polyethylenes differ in density by from 0.030 to 0.048 g/cm³.

[0014] In another embodiment, the invention provides a rotomolded article formed from or including a polyethylene composition, the polyethylene composition including a first polyethylene having a melt index of 0.4 to 3.0 g/10 min and a density of from 0.910 to 0.930 g/cm³; and a second polyethylene having a melt index of 10 to 30 g/10 min and a density of 0.945 to 0.975 g/cm³, wherein the composition has a density of from 0.930 to 0.955 g/cm³ and a melt index of 1.5 to 12 g/10 min, and wherein the first and second polyethylenes differ in density by from 0.030 to 0.048 g/cm³.

[0015] In another embodiment, the invention provides a rotomolded article formed from or including a polyethylene composition, the polyethylene composition including a first metallocene-catalyzed polyethylene having a melt index of 0.4 to 3.0 g/10 min and a density of from 0.910 to 0.930 g/cm³; and a second metallocene-catalyzed polyethylene having a melt index of 10 to 30 g/10 min and a density of 0.945 to 0.975 g/cm³, wherein the composition has a

density of from 0.930 to 0.955 g/cm³ and a melt index of 1.5 to 12 g/10 min, and wherein the first and second polyethylenes differ in density by from 0.030 to 0.048 g/cm³.

[0016] In another embodiment, the invention provides a process for forming a rotomolded article, the process carried out by: (a) providing a polyethylene composition, the polyethylene composition including a first polyethylene having a melt index of 0.4 to 3.0 g/10 min and a density of from 0.910 to 0.930 g/cm³; and a second polyethylene having a melt index of 10 to 30 g/10 min and a density of 0.945 to 0.975 g/cm³, wherein the composition has a density of from 0.930 to 0.955 g/cm³ and a melt index of 1.5 to 12 g/10 min, and wherein the first and second polyethylenes differ in density by from 0.030 to 0.048 g/cm³; and (b) rotomolding the composition to form a rotomolded article.

[0017] In another embodiment, the invention provides a process for forming a rotomolded article, the process carried out by: (a) providing a polyethylene composition, the polyethylene composition including a first metallocene-catalyzed polyethylene having a melt index of 0.4 to 3.0 g/10 min and a density of from 0.910 to 0.930 g/cm³; and a second metallocene catalyzed polyethylene having a melt index of 10 to 30 g/10 min and a density of 0.945 to 0.975 g/cm³, wherein the composition has a density of from 0.930 to 0.955 g/cm³ and a melt index of 1.5 to 12 g/10 min, and wherein the first and second polyethylenes differ in density by from 0.030 to 0.048 g/cm³; and (b) rotomolding the composition to form a rotomolded article.

[0018] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that each of the first and second polyethylenes has an Mw/Mn ratio of from 1.4 to 4.0.

[0019] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that each of the first and second polyethylenes has an Mw/Mn ratio of from 1.8 to 3.5.

[0020] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in

accordance with any of the preceding embodiments, except that the first polyethylene has a density of from 0.911 to 0.926 g/cm³.

[0021] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that the second polyethylene has a density of from 0.950 to 0.970 g/cm³.

[0022] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that the second polyethylene has a density of from 0.955 to 0.965 g/cm³.

[0023] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that the composition has a density of from 0.932 to 0.950 g/cm³.

[0024] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that the composition has a density of from 0.935 to 0.945 g/cm³.

[0025] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that the first and second polyethylenes differ in density by from 0.032 to 0.045 g/cm³.

[0026] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that the first and second polyethylenes differ in density by from 0.035 to 0.042 g/cm³.

[0027] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, except that the composition has a melt index I_{2.16} of from 2 to 10 g/10 min.

[0028] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in

accordance with any of the preceding embodiments, wherein the blend includes 80% to 20% by weight of the first polyethylene and 20% to 80% by weight of the second polyethylene, based on the total weight of the first and second polyethylenes.

[0029] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein the blend includes 65% to 35% by weight of the first polyethylene and 35% to 65% by weight of the second polyethylene, based on the total weight of the first and second polyethylenes.

[0030] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein the blend includes 55% to 45% by weight of the first polyethylene and 45% to 55% by weight of the second polyethylene, based on the total weight of the first and second polyethylenes.

[0031] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein the composition has an ESCR value of at least 250 hr.

[0032] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein the composition has an ESCR value of at least 500 hr.

[0033] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein the composition has an ESCR value of at least 750 hr.

[0034] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein the composition has an ESCR value of at least 1000 hr.

[0035] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein the composition has an Izod impact strength of at least 120 kJ/m, for a 3.17 mm sample at -40°C .

[0036] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments, wherein at least one of the first and second polyethylenes is a blend of two or more polyethylene resins.

[0037] In another embodiment, the invention provides a polyethylene composition, a rotomolded article, or a process of forming a rotomolded article, in accordance with any of the preceding embodiments except the immediately preceding embodiment, wherein the composition includes only the first and second polyethylenes, except that minor amounts of conventional additives can also be present.

5. BRIEF DESCRIPTION OF THE DRAWINGS

[0038] Fig. 1 is a Differential Scanning Calorimetry (DSC) display of the polymer melting temperature of two blend compositions. The solid line represents a blend according to the invention (3a-b in Table 1) and the broken line represents a Comparative blend (5a-b in Table 1).

6. DETAILED DESCRIPTION

[0039] As indicated above, previous work has often centered on film and blowmolding applications. Thus, prior studies were often directed to film clarity, puncture resistance and processing characteristics for film processing, such extrusion and blown film processes. ESCR improvement was also often addressed for the use of blended polyethylenes for such applications, especially in blowmolding applications. However, the prior art fails to provide polyethylene blend compositions for the specialized technology and particular product requirements of rotomolding. The inventive compositions surprisingly and advantageously provide improved ESCR and significantly improved IZOD impact properties, enhancing the overall value of the invention compositions.

[0040] By preparing several samples of proposed blend polyethylene components and then subjecting blends prepared from them to analytical testing, it was determined that peak values of ESCR are obtained when the difference in density and melt index ($I_{2.16}$) of the blend components were within specific ranges, as described herein. At smaller density differences for the two components, ESCR was improved over single component compositions, but was significantly deficient to those within the range for the inventive compositions. Increasing the width of the density range between the components within the invention range increased the ESCR improvement until a peak was reached in which ESCR no longer improved and began to diminish. Examining the melting peaks of the sample blends with a differential scanning calorimeter (DSC) helps illustrate the region in which ESCR improvements are no longer realized by increasing the difference in densities between the two components. This is shown by the point where by further increasing the width of the density range, the two components no longer completely cocrystallize, as evidenced by the presence of a secondary lower melting peak in the DSC scan. When the density range was wider than that described above, evidence of loss of cocrystallizability became apparent as a second melting peak or shoulder began to appear in the scans. The blends exhibiting even minimal incidence of a second shoulder had diminished ESCR improvements. See FIG. 1, and TABLE 1.

[0041] The first polyethylene of the polymer blends of the invention is a linear low density polyethylene copolymer derived from the coordination polymerization of principally ethylene with a minor amount of one or more copolymerizable monomers. Particularly improved end-product properties are obtained using such copolymers having a narrow molecular weight distribution (M_w/M_n , or "MWD"), e.g., M_w/M_n of from a lower limit of 1.4 or 1.8 or 2.0 to an upper limit of 4.0 or 3.5 or 3.0, with ranges from any lower limit to any upper limit being contemplated. Suitable comonomers include C_3 - C_{20} alpha-olefins, preferably C_3 - C_8 , C_5 - C_{20} cyclic olefins, preferably C_7 - C_{12} cyclic olefins, C_7 - C_{20} vinyl aromatic monomers, preferably styrene, and C_4 - C_{20} geminally disubstituted olefins, preferably isobutylene. The most preferred comonomers include propylene, 1-butene, 1-hexene, 4-methyl-1-pentene and 1-octene. The density of the copolymer

is determined largely by comonomer content and typically ranges from 0.910 or 0.911 g/cm³ to 0.930 or 0.926 g/cm³, with ranges from any lower limit to any upper limit being contemplated. Some amount of long-chain branching may be present, but the density limitations are largely due to the presence of comonomer. These ethylene copolymers are of higher molecular weight than the second polyethylene of the blends, as shown by a melt index I_{2.16} as measured according to ASTM D1238, condition 190 °C, 2.16 kg (formerly condition "E"), of from about 0.4 to about 3.0 g/10 min. This molecular weight range is approximately equivalent to an intrinsic viscosity (in decalin at 135 °C) of from about 1.2 to about 1.7 dl/g.

[0042] The second polyethylene of the polymer blends of the invention is a high density polyethylene of similar Mw/Mn to the first polyethylene, *i.e.*, Mw/Mn of from a lower limit of 1.4 or 1.8 or 2.0 to an upper limit of 4.0 or 3.5 or 3.0, with ranges from any lower limit to any upper limit being contemplated, but with lower molecular weight. It will be derived from ethylene and, optionally, minor amounts of any of the comonomers listed above for the first polyethylene. The density can be from a lower limit of 0.945 or 0.950 or 0.955 g/cm³ to an upper limit of 0.975 or 0.970 or 0.965 g/cm³, with ranges from any lower limit to any upper limit being contemplated. The lower molecular weight is shown by a melt index I_{2.16} as measured according to ASTM D1238, condition 190 °C, 2.16 kg, of from 10 to 150 g/10 min. This molecular weight range is approximately equivalent to an intrinsic viscosity (in decalin at 135 °C) of from about 0.9 to about 1.2 dl/g. The melt index I_{2.16} of the second polyethylene can range from a lower limit of 10 or 12 or 14 g/10 min to an upper limit of 150 or 100 or 50 or 30 g/10 min, with ranges from any lower limit to any upper limit being contemplated.

[0043] Industrial methods of producing the polyethylene components of the invention are well known in the art as is exemplified in the references cited above. Any such method capable of producing polyethylene polymer components according to the invention will be suitable. Such methods include gas phase, liquid phase (or solution), and slurry phase polymerization processes, either alone or in combination. By alone, reference is made to series or serial production in a single reactor or in more than one reactor. Reactor blends will also be suitable,

such as by the use of mixed catalysts or mixed polymerization conditions in a single reactor. Gas phase processes are particularly suited in view of economic advantages. Such processes use supported catalysts and are conducted in polymerization reactors under gas phase conditions suitable for linear low density ethylene copolymers prepared by coordination polymerization. Illustrative examples may be found in U.S. Patent Nos. 4,543,399, 4,588,790, 5,028,670, 5,352,749, 5,382,638, 5,405,922, 5,422,999, 5,436,304, 5,453,471, 5,462,999 and 5,463,999, and International applications WO 94/28032, WO 95/07942 and WO 96/00245. These processes use either traditional Ziegler-Natta catalysts or later organometallic catalysts characterized as having essentially single polymerization sites due to the arrangement of ancillary ligands on or about the metal center. Metallocene catalysts are representative "single site catalysts" and are preferred in this invention for their ability to produce narrow molecular weight distribution polyolefins. Typically, the processes are conducted at temperatures of from about -100 °C to 150 °C, more typically from about 40 °C to 120 °C, at pressures up to about 7000 kPa, typically from about 690 kPa to 2415 kPa. Continuous processes using fluidized beds and recycle streams as the fluidizing medium are preferred.

[0044] Slurry polymerization processes are suitable for both components and particularly suited for the high density components of the invention. These processes are typically described as those in which the polymerization medium can be either a liquid monomer, like propylene, or a hydrocarbon solvent or diluent, advantageously aliphatic paraffin such as propane, isobutane, hexane, heptane, cyclohexane, etc. or an aromatic one such as toluene. Slurry solids typically include the forming polymer and inert carrier-supported catalysts. Catalysts are typically Ziegler-Natta, and/ or one or more single site catalysts, such as metallocenes. The polymerization temperatures may be those considered low, e.g., less than 50 °C, typically 0 °C-30 °C, or may be in a higher range, such as up to about 150 °C, typically from 50 °C up to about 80 °C, or at any ranges between the end points indicated. Pressures can vary from about 100 to about 700 psia (0.76-4.8 MPa). Additional description is given in U.S. Patent Nos. 4,182,810, 5,274,056, 6,319,997, 6,380,325, 6,420,497, WO 94/21962 and WO 99/32531.

[0045] The polyethylene blend compositions in accordance with the present invention can include the first polyethylene in an amount of from a lower limit of 20 or 35 or 45 wt% to an upper limit of 80 or 65 or 55 wt%, based on the total weight of the first and second polyethylenes, with ranges from any lower limit to any upper limit being contemplated. Similarly, the polyethylene blend compositions in accordance with the present invention can include the second polyethylene in an amount of from a lower limit of 20 or 35 or 45 wt% to an upper limit of 80 or 65 or 55 wt%, based on the total weight of the first and second polyethylenes, with ranges from any lower limit to any upper limit being contemplated.

[0046] Additionally, either or both of the first polyethylene and the second polyethylene can be a sub-blend of two or more polyethylenes so long as the sub-blend has the properties described herein.

[0047] Although the description herein focuses on first and second polyethylenes, in some embodiments, the polyethylene blend composition can further include additional polymeric components, including additional polyethylenes, provided that the overall blend composition has the recited properties.

[0048] The weight percentages recited herein for the first and second polyethylene components are based on the total weight (100%) of the first and second polyethylene components.

[0049] The blend can have a density of from a lower limit of 0.930 or 0.932 or 0.935 g/cm³ to an upper limit of 0.955 or 0.950 or 0.945, with ranges from any lower limit to any upper limit being contemplated.

[0050] The blend can have a difference in the density of the first and second polyethylenes of from a lower limit of 0.030 or 0.032 or 0.035 g/cm³ to an upper limit of 0.048 or 0.045 or 0.042 g/cm³, with ranges from any lower limit to any upper limit being contemplated.

[0051] The melt index of the blend can be from a lower limit of 1.5 or 2.0 g/10 min to an upper limit of 12 or 10 or 8 g/10 min.

[0052] Polyethylene blend compositions of the invention show ESCR values of greater than 250 or greater than 500 or greater than 750 or greater than 1000 hr.

[0053] Polyethylene blend compositions of the invention show Notched Izod Impact values (-40 °C, 3.17 mm thick sample) of greater than 120 kJ/m.

[0054] Additives may be used as needed. Typical additives include one or more of antioxidants, anti-static agents, UV stabilizers, foaming agents, processing aids, nucleating agents, nanocomposites, fiber reinforcements and pigments. Illustrative pigments or colorants include titanium dioxide, carbon black, cobalt aluminum oxides such as cobalt blue, and chromium oxides such as chromium oxide green. Pigments such as ultramarine blue, which is a silicate. Phthalocyanine blue and iron oxide red will also be suitable. Such are typically used in amounts from 0 wt% to not more than about 15 wt%, based on the total weight of the first and second polyethylene components.

[0055] In accordance with the invention, a polyolefin-based, resin blend as previously described, is rotomolded. To this end, the resins, with or without additives, may be extrusion blended, pelletized and ground to a powder, typically of 35 U.S. mesh (500 µm) which means that the average particle size is typically 60 U.S. mesh (250 µm). A suitable extrusion blending temperature is typically about 190 to 210 °C. Thereafter, the powder is placed inside a hollow mold, which is typically rotated on two axes and heated inside an oven. The powder is heated for a sufficient time and at a temperature adequate to melt the thermoplastic constituents of the powder blend, during the rotomolding. The time and temperature used depend upon factors including the thickness of the part being rotomolded and thermal sensitivity of the constituents, and one skilled in the art can readily determine suitable processing conditions. As applied to the polyethylene resin blends of the invention, a part thickness of about 1/8" (0.3175 cm), an oven temperature setting ranging from about 550 °F to 650 °F. (287.8 to 343.3 °C) for about 10 to 20 minutes will typically provide sufficient melting conditions.

7. EXAMPLES

[0056] Notched IZOD tests were conducted in accordance with ASTM D-256, Method A.

[0057] M_z , M_w and M_n can be measured using gel permeation chromatography (GPC), also known as size exclusion chromatography (SEC). This technique utilizes an instrument containing columns packed with porous beads, an elution solvent, and detector in order to separate polymer molecules of different sizes. In a typical measurement, the GPC instrument used is a Waters chromatograph equipped with ultrastyro gel columns operated at 145 °C. The elution solvent used is trichlorobenzene. The columns are calibrated using sixteen polystyrene standards of precisely known molecular weights. A correlation of polystyrene retention volume obtained from the standards, to the retention volume of the polymer tested yields the polymer molecular weight.

[0058] Average molecular weights M can be computed from the expression:

$$M = \frac{\sum_i N_i M_i^{n+1}}{\sum_i N_i M_i^n}$$

where N_i is the number of molecules having a molecular weight M_i . When $n = 0$, M is the number average molecular weight M_n . When $n = 1$, M is the weight average molecular weight M_w . When $n = 2$, M is the Z-average molecular weight M_z . The desired MWD function (e.g., M_w/M_n or M_z/M_w) is the ratio of the corresponding M values. Measurement of M and MWD is well known in the art and is discussed in more detail in, for example, Slade, P. E. Ed., *Polymer Molecular Weights Part II*, Marcel Dekker, Inc., NY, (1975) 287-368; Rodriguez, F., *Principles of Polymer Systems 3rd ed.*, Hemisphere Pub. Corp., NY, (1989) 155-160; U.S. Patent No. 4,540,753; Verstrate et al., *Macromolecules*, vol. 21, (1988) 3360; and references cited therein.

[0059] Environmental Stress Crack Resistance (ESCR) (bent strip) is determined in accordance with ASTM D 1693, condition B, 10% IGEPAL™. IGEPAL™ is a nonylphenoxy poly(ethylenoxy)ethanol surfactant available from Rhone Polenc, Cranbury, NJ. All ESCR values cited herein are ASTM D 1693 condition B, 10% IGEPAL™ F50 values, and are given in units of hours.

[0060] Polymer density (g/cm^3) is determined using a compression molded sample, cooled at 15 °C per hour and conditioned for 40 hours at room temperature according to ASTM D1505-68 and ASTM D1928, procedure C.

[0061] Polymer melt flow rates can be determined at 190 °C according to ASTM D-1238. $I_{21.6}$ is the "flow index" or melt flow rate of the polymer measured according to ASTM D-1238, condition 190 °C, 21.6 kg, and $I_{2.16}$ is the "melt index" or melt flow rate of the polymer measured according to ASTM D-1238, condition 190 °C, 2.16 kg. The ratio of $I_{21.6}$ to $I_{2.16}$ is the "melt flow ratio" or "MFR". The melt flow rate $I_{21.6}$ is also sometimes termed the "high load melt index" or HLMI. Melt flow rates are reported in units of grams per 10 minutes (g/10 min) or equivalently decigrams per minute (dg/min).

Examples 1-3, Comparative Examples 1-5

[0062] The examples shown in Table 1 were prepared generally in accordance with the examples in U.S. Patent No. 5,382,631, except where noted. A zirconocene activated with alumoxane on a silica support, 12 wt% methylalumoxane and 3.5 wt% zirconium, was used as polymerization catalyst in a gas phase reactor operated at about 185 °F (85 °C), with a gas phase consisting of 70 vol% ethylene, 0.5 - 2.0 vol% hexene, 200-800 parts per million hydrogen, with remainder being nitrogen. From about 50 to 75 pounds (22.6 to 33.9 kg) per hour were produced in each polymerization run.

[0063] Table 1 illustrates the invention in examples 1a-b through 3a-3b, with comparative examples Comp 1 through Comp 5a-b. Each "a" row illustrates a first polyethylene component and each "b" row illustrates a second polyethylene component. The column " Δ density" provides the difference in density of the two components for each illustrated blend. Comp 1 illustrates a comparative single polyethylene component within the density and melt index range typical for rotomolding compositions. Comp 2 illustrates a comparative blend where the melt indexes of the two components are approximately equal and the densities are such that the difference is less than 0.030 g/cm³ but the average is the same as that of Comp 1. Comp 3 illustrates a comparative blend where the high molecular weight first and low molecular weight second polyethylenes each have the same density as Comp 1. Comp 4 illustrates a comparative blend where densities are the same but the molecular weight of the high molecular weight fraction and the blend composition have been increased. Comp 5 illustrates a comparative blend

where the high molecular weight first polyethylene component has a density below 0.910 g/cm^3 . As is readily apparent, the invention examples each have excellent ESCR and the comparative examples each do not.

Table 1

Example	Wt%	Melt Index $I_{2.16}$ (g/10 min)	Density (g/cm^3)	Δ density (g/cm^3)	Mw/Mn	ESCR, F_{50} (hr)
1a	48.4	0.86	0.919		2.43	
1b	51.6	14.0	0.950		3.34	
1a/1b Blend	100	2.7	0.935	0.031		>1000
2a	45	0.86	0.919		2.43	
2b	55	14.0	0.950		3.34	
2a/2b Blend	100	3.1	0.936	0.031		>1000
3a	38.5	0.46	0.911		2.50	
3b	61.5	14.0	0.950		3.34	
3a/3b Blend	100	2.9	0.935	0.039		>1000
Comp 1	100	3.05	0.935		2.82	<220
Comp 2a	55.5	3.0	0.947		2.87	
Comp 2b	45.5	2.88	0.920		2.43	
Comp 2a/2b Blend	100	3.0	0.935	0.027		<180
Comp 3a	58	0.97	0.934		2.93	
Comp 3b	42	14	0.934		2.58	
Comp 3a/3b Blend	100	3.0	0.934	0		<250
Comp 4a	48	3.0	0.935		2.82	
Comp 4b	52	14	0.934		2.58	
Comp 4a/4b Blend	100	7.6	0.935	0.01		<100
Comp 5a*	30	1.2	0.900		2.0	
Comp 5b	70	14	0.950		3.34	
Comp 5a/5b Blend	100	7.6	0.935	0.050		<100

*Commercial ethylene-based hexene plastomer (ExactTM 3132, ExxonMobil Chemical)

[0064] As further illustrated in FIG. 1, Comparative example 5a-b (dotted line) exhibits dual melting temperatures by DSC, at 95.9°C and 127.7°C . Invention example 3a-b (solid line) exhibits a single melting temperature at 128.4°C . Both

of these compared examples have the same density, indicative of essentially equivalent average comonomer content, yet cocrystallization is effectively achieved only with the invention blend.

Examples 4-5, Comparative Example 6

[0065] The examples 4 and 5 of Table 2 were prepared by melt blending two selected components in accordance with the invention. The high molecular weight first polyethylene used was a commercial film grade ethylene-based hexene copolymer (Exceed™ 1023CA, ExxonMobil Chemical Company) and the low molecular weight second polyethylene was produced in an ExxonMobil Chemical commercial slurry loop reactor utilizing a silica supported zirconocene activated with methylalumoxane polymerization catalyst under conditions used to produce high density polyethylene. The blend and comparative examples of Table 2 additionally included approximately equivalent amounts of additives: Irganox™ 3114 primary antioxidant (CIBA); Irgafos™ 168 secondary antioxidant (CIBA); and acid neutralizer (zinc stearate, or equivalent). The density, melt index $I_{2.16}$ and Mw/Mn of both are shown below. Comp 6 is a comparative example illustrating the properties of a commercial single component LLDPE resin sold for rotational molding use and described as having excellent ESCR and toughness. Examples 4 and 5 additionally exhibited low High Load Melt Indexes, $I_{21.6}$, ASTM-D 1238 (190 °C, 21.6 kg) of 17.9 each as compared to the Comp 6 sample value of 82.5.

[0066] As can be seen in Table 2, both the ESCR and Notched Izod properties show significant improvements over the comparison composition. The ESCR values for invention examples 4 and 5 are reported as >288 hr in that the testing was stopped at 288 hours. It can be reasonably anticipated that the total performance would have matched that of the Table 1 invention samples if the testing were run for as long a period of time. Additional data obtained indicated that the invention blends of Table 2 exhibited surprisingly improved ARM (drop weight) impact strength, flexural modulus and tensile break stress as compared to the comparison composition.

TABLE 2

Example	Wt%	Melt Index I _{2.16} (g/10 min)	Density (g/cm ³)	Δ density (g/cm ³)	Mw/Mn	ESCR, F ₅₀ (hr)	Notched Izod, -40°C (ft-lb/in) (kJ/m)	
							3.17 mm**	6.35 mm**
4a	55	1.0	0.923		2.9			
4b	45	21.2	0.958		2.7			
4a/4b Blend	100	3.0	0.939	0.035	3.2	>288	2.58 137.8	1.62 86.5
5a	45	1.0	0.923		3.1			
5b	55	21.2	0.958					
5a/5b Blend	100	3.7	0.942	0.035	3.1	>288	1.97 105.2	1.5 80.1
Comp 6*	100	3.3	0.939		3.6	52	1.94 103.6	1.20 64.1

* Commercial LLDPE of ethylene and hexene (LL 8460, ExxonMobil Chemical)

** sample thickness

[0067] Various tradenames used herein are indicated by a TM symbol, indicating that the names may be protected by certain trademark rights. Some such names may also be registered trademarks in various jurisdictions.

[0068] All patents, test procedures, and other documents cited herein, including priority documents, are fully incorporated by reference to the extent such disclosure is not inconsistent with this invention and for all jurisdictions in which such incorporation is permitted.